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OFFICE OF CONTRACT ADMINISTRATION
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Date: August 27, 1979

Project Title: Experimental Verification of Internal Dosimetry Calculators

Project No: E-26-648 Green card

Project Director: Dr. John W. Poston

Sponsor: Department of Energy; Oak Ridge Operations; Oak Ridge, TN 37830

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OFFICE OF CONTRACT ADMINISTRATION

SPONSORED PROJECT TERMINATION

Date: September 27, 1980

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Project No: E--26-648

Project Director: Dr. John W. Poston

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Proposed Research - Summary of Progress

During the past year a dosimetry research program has been established in the School of Nuclear Engineering at the Georgia Institute of Technology. The major objective of this program has been to provide research results upon which a useful internal dosimetry system could be based. The important application of this dosimetry system will be the experimental verification of internal dosimetry calculations such as those published by the MIRD Committee.

The research has been divided into several distinct areas. These are:

A. Investigation of the TL response characteristics of CaF_2, LiF, $Li_2B_4O_7$, and $CaSO_4$ phosphors in organic liquids which may be suitable for molding organs for use in internal dosimetry. Preliminary results are available for CaF_2:Dy and LiF in solvents which will be used to recover the phosphors from the PAC-TLD paste mixture. Preliminary results indicate that the solvents will have minimal effect on the TL response of CaF_2:Dy or LiF. However, small changes in response may have been undetected in this initial study. A more detailed study is underway at this time in liquid alkyl-chlorides and additional solvents. These results will be combined with the preliminary results for publication in the open literature.[14]

In an effort to conserve research funds all experiments involving $CaSO_4$:Dy will use crystals grown in the laboratory. The technique of Bapat[15] which is a modification of that reported by Yamashita et al.[16] has been studied at Georgia Tech. This TL phosphor can be produced at a relatively low cost from essentially reagent grade materials. At the present time large

batches of $CaSO_4$:Dy crystals can be produced in our laboratory for use in the research.

B. Investigation of mixing and molding techniques applicable to the preparation of the molded target organs similar to those introduced by Feher and his colleagues. Large samples of an n-alkyl chloride have been obtained from a commercial vendor and molding investigations have begun. Initial results indicate that few problems will be encountered. To date the PAC paste has been prepared, without TL phosphors present, in glass and metal molds. The ease with which this phase of the research has advanced indicates that progress in this area will be much more rapid than previously estimated.

For the above reasons, the major effort during the next period will be directed toward studying the following:

1) study of the uniformity of mixing of TLD powder on the PAC mixture

2) determination of methods for recovering the powder from organs, etc., and

3) study of the recovery efficiency for the TLD material from the molded material.

In addition, other methods and/or procedures to accomplish these tasks, which may have been identified during the course of this study, will be investigated.

C. Investigation into other methods of dosimetry which may be applicable to the specific problem. During the past year three literature surveys have been completed which are related in some manner to the area of interest. First, a careful survey of the

nuclear medicine literature has been completed.[17] This survey was intended to collect information necessary to identify organs and radionuclides which should be studied in subsequent experiments.

A second literature survey has been completed on thermoluminescent dosimetry. This survey has concentrated primarily on LiF (although information on other phosphors has been collected) and was intended to cover progress in the area since the last thermoluminescent dosimetry bibliography.[18] This survey has been completed.

The third literature survey was intended to identify other techniques applicable to measuring "organ-averaged" doses in heterogeneous phantoms. This survey is at present underway but should be completed in the near future. It has concentrated primarily on chemical dosimetry techniques.

D. Establishment of a computer capability to provide Monte Carlo calculated results for comparison to the experiments. For the present this task is essentially complete. The computer program ALGAM[19] has been installed on the Georgia Tech computer. Test cases supplied with the program package have been run and results indicate that the code is functioning normally. A second computer code, TECALC,[20] has also been installed on the computer system. This code is used to compare tissue-, bone-, and lung-equivalent materials to the Snyder-Fisher formulation for these regions used in the Monte Carlo code. Primary effort over the last several months has been directed toward comparison of

normally accepted "equivalent materials" to the Snyder-Fisher formulations.

As stated in the original proposal, the code DISDOS[21] has been compiled, debugged and is running properly on the CDC Cyber Model 74 computer. This code which is an earlier version of ALGAM will be used only as a backup to the more extensive ALGAM code.

Research Goals for the Renewal Period

Current progress in this research area, coupled with the anticipated progress in the remaining two months of the project, indicate that the research goals for the renewal period should be set for an 18-month period. This period was selected over the more conventional 12-month period to allow optimum continuity to the project. The acquired continuity should allow the completion of this project in less than the 3-year period previously anticipated. It is anticipated that experiments in the heterogeneous phantom using internal source organs could be underway late in the second year of this study. Any interuption or delay in this phase of the research (i.e., the primary objective) would be counter-productive. For the above reasons, this section presents research goals to be accomplished within an 18-month period beginning August 1, 1980. In addition, the budget presented at the end of this section is structured for this extended time period.

Specific Research Goals (18-month period)

A. Prepare PAC-TLD dosimetry system for use in phantom exposures based on results of TL response study. Characteristics to be studied early in the renewal period include:

1) TL response as a function of concentration in the material in which it is to be suspended.

EXPERIMENTAL VERIFICATION OF INTERNAL DOSIMETRY CALCULATIONS

Annual Progress Report
(Contract No. DE-AS05-79EV 10248)

May 1980

School of Nuclear Engineering
Georgia Institute of Technology
Atlanta, Georgia 30332

INTRODUCTION

In 1968 the first publications of the Medical Internal Radiation Dose (MIRD) Committee of the Society of Nuclear Medicine appeared in the open literature. One of the most significant of these early publications was Pamphlet No. 5 which presented estimates of absorbed fractions for monoenergetic photon sources uniformly distributed in various organs of a heterogeneous phantom.[1] This pamphlet presented the first estimates of absorbed fractions which were obtained in a realistic representation of the adult human body. Needless to say, such estimates were much needed in nuclear medicine and were quickly accepted and used in the profession.

Other publications, presenting changes and modifications to the phantom, followed over the ensuing years.[2,3] However, the fact remained that there was little effort devoted to the experimental checking of these calculated results. This fact did not deter the increased and ubiquitous use of these data.

There still remains a great need to perform dosimetry measurements for the purpose of verifying these internal dosimetry calculations. To date, those experiments performed with this objective have met with only limited success. The need for better dosimetric data has been determined to be so great that the National Council on Radiation Protection and Measurements (NCRP) has established a scientific committee (Committee 55) to study this area.[4]

A dosimetry research project was established at Georgia Tech within the last year to provide data for intercomparison with internal dosimetry calculations. The goal of this project was to formulate a dosimetry system which would provide absorbed doses averaged over the entire volume of the

target organ within the phantom. Previous techniques had not provided such information. This document presents a summary of progress on this research project over the first ten months of the period.

Summary of Previous Research

There have been several efforts to provide limited experimental data for comparison to calculational results obtained in the MIRD phantom.* However, these experiments have suffered from several shortcomings which have made comparisons of experimental and calculational results very difficult. Nevertheless, in selected organs for selected exposure situations, the agreement has been good.

There have been basically three approaches taken to provide data for comparisons. At least two groups have used point measurements in homogeneous regions of a phantom and derived organ-averaged doses from these measurements.[5,6,7,8,9] Stansbury[10] measured photon spectral distributions at selected positions in the MR. ADAM phantom and calculated organ-averaged doses based on this information.

A second method was employed by Jones and his colleagues.[11] In this study Jones et al. investigated their ability to estimate absorbed dose in the liver, due to Tc-99m sulfur colloid, from measurements made on the exterior surface of the patient. Experiments performed on a MR. ADAM phantom agreed well with calculations. In addition, checks in patients agreed within about 30% with calculated results as long as the patient was close to the phantom size. For non-standard patients the discrepancies were much larger.

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*This phantom, developed by W. S. Snyder and H. L. Fisher, Jr., is known also as the Snyder-Fisher phantom and later versions were called MR. ADAM.

Feher and his colleagues[12] reported on a study in a modified BOMAB phantom which utilized LiF thermoluminescent powder suspended in an organic matrix as a dosimetry system. This study was limited to two radioactive sources (I-131 and Co-60) and two sources organs (the thyroid gland and testicles). These authors attempted to measure volume averaged dose by utilizing a PAC-TL paste to construct organ shapes. The calculated results agreed with the measured results within about 30%. However, similar calculations in the Snyder-Fisher phantom were nearly 50% lower for the Co-60 source and more than a factor of two lower for the I-131 source. These results are not too surprising since the BOMAB phantom is not truly representative of the Snyder-Fisher phantom.

At the present time all internal dosimetry calculations are designed to provide estimates of the average absorbed dose to the organs of interest. This concept, i.e. an average absorbed dose over the organ, is the result of our lack of knowledge as to the microscopic distribution of the radioactive material in the organ as well as the failure (or inability) to identify critical cells within the target organs in more detail. Thus, the problem of verifying internal dosimetry calculations might be advanced if there were available a "volume detector" which could be shaped to represent the organs of the body.

One possible solution might be to form a hollow shell representing each organ from a material such as polystyrene and then fill the organ with an aqueous chemical dosimeter. Such an arrangement would have the major advantage of providing a dosimeter which is essentially tissue equivalent and would match closely the remainder of the tissue-equivalent filling of the phantom. The disadvantages are that, in general, chemical dosimetry systems require a very high exposure and their use requires meticulous care

and cleanliness. The use of very intense radiation sources (in order to produce the doses required) makes the use of most chemical dosimetry systems unattractive. However, at least one system, the tetrachloroethylene-water two-phase dosimetry system has been used in the 2-12 rad dose range and deserves further study for this application.[13]

The technique reported by Feher and colleagues[12] has shown some promise as a possible solution to this complex dosimetry problem. However, much more research is required before this technique can be used widely in this area of dosimetry. These authors used a mixture of paraffin, n-alkyl chloride, and TLD powder (PAC-TLD) to form organ shapes for use in dosimetry experiments. They reported only a few results in the literature and further contact with them in the last year has indicated that there has been no further development of this method since about 1976. However, Feher has indicated that the method is very promising and that the research had been terminated because of funding problems and not because of insurmountable technical problems.

Before this method can be applied widely to the experimental determination of internal exposure conditions additional research will be required. There has been some indication that the thermoluminescence properties of TLD materials may be changed after contact with liquids. For example, LiF has been suspended (or surrounded) in organic liquids with high hydrogen content in order to increase the TL response to fast neutrons.[14,15] Puite[16] performed a similar study with CaF_2 (Mn) suspended in organic liquids. Spurny and his colleagues[17] studied the effects on TL response of suspending LiF in water. The mechanism of the changes in response of TL materials in these liquids is not completely clear. The effects on TL response of suspending a TLD powder in an organic

matrix (such as PAC) to mold "dosimetric organs" has not been investigated.

Summary of Progress

During the past year a dosimetry research program has been established in the School of Nuclear Engineering at the Georgia Institute of Technology. The major objective of this program has been to provide research results upon which a useful internal dosimetry system could be based. The important application of this dosimetry system will be the experimental verification of internal dosimetry calculations such as those published by the MIRD Committee. Each research area and the results obtained to date will be discussed below.

A. Investigation of TL Response Characteristics

In this phase of the research the effects of organic solvents and other liquids on TLD response were to be investigated. Materials to be studied included CaF_2, LiF, $Li_2B_4O_7$, and $CaSO_4$ phosphors. Organic liquids to be studied included those solvents which may be used to recover the phosphors from the PAC-TLD paste mixture.

Initially TLD hot-pressed chips were studied in an attempt to identify any gross change which may have been caused by the solvents. Hot-pressed chips were selected to allow the research assistants an opportunity to become familiar with the TLD reader systems and to allow time for modifications to a Harshaw TLD reader (obtained from ORNL). This reader was being modified to accept TLD powders which would be used in the PAC-TLD paste.

The initial experiments involved the solubility and response characteristics of two TLD materials in two solutions. The solutions selected were ethyl alcohol and benzene. The TLD materials were LiF (TLD-100) and

CaF_2 (TLD-200) and both the hot-pressed chip (1/8" x 1/8" x 0.035") and the rods (1 x 1 x 6 mm) were used in the study. It was recognized that hot pressed chips had different characteristics than did TLD powder (e.g. LiF powder has a density of ~ 1.3 g/cm^3 while the TLD-100 chips have a density of ~ 2.6 g/cm^3), however, it was thought that such studies would reveal any solvents which should be eliminated due to extreme alteration of the response of the TLD material.

In the experiment the TLDs were fully annealed (LiF - one hour @ 400°C and CaF_2 - one hour @ 350°C). Each was weighed individually and placed in a small polyethylene vial in which it was stored and irradiated. All dosimeters were exposed (dry) to a beta-shielded 10 mg Ra-226 source in air. Half of each type were given an exposure of 250 mR while the other half received an exposure of 25 mR. After irradiation, those TLDs of the same type and exposure level were split - half being put into 5 cc of ethyl alcohol and half being kept dry. The TLDs were stored for three days during which the containers were shaken routinely to assure complete wetting.

Following this soaking period, the TLDs were removed from their containers and air dried. This required about one half-hour. The dosimeters were reweighed and read either on a Victoreen Model 2800 TLD reader or on a Victoreen Model 2810 TLD reader. These data are given in Tables I and II.

The data presented in these two tables were tested for difference between the variances of the two samples. For LiF (Table I) the analysis showed that there was no significant difference (at the 95% confidence level) between the sets of data. However, a similar analysis of the data for CaF_2 (Table II) showed that the difference between the two sets of data was significant. The apparent increase in reading of the CaF_2 rods is at

Table I. Effects of Solvents on LiF (TLD-100) Response

SOLVENT: ETHYL ALCOHOL

TIME IN SOLUTION: 3 DAYS

TLD	Wt. Before (mg)	Wt. After (mg)	Status*	Reading**	Avg.
A (LiF,chip)					
1	23.11	23.14	250-D	334+	296± 60
2	23.12	23.12	250-D	327	
3	22.96	22.90	250-D	227	
4	23.82	23.85	250-W	334	328± 7
5	23.01	22.98	250-W	330	
6	23.20	23.23	250-W	321	
7	23.16	23.15	25-D	064	64± 2
8	23.42	23.47	25-D	062	
9	23.15	23.14	25-D	065	
10	23.12	23.12	25-W	063	62± 4
11	23.20	23.18	25-W	066	
12	23.22	23.14	25-W	058	
B (LiF,rod)					
1	15.64	15.61	250-D	313++	349± 32
2	15.08	15.05	250-D	359	
3	15.27	15.24	250-D	374	
4	15.48	15.44	250-W	353	361± 30
5	15.06	14.97	250-W	394	
6	15.05	14.93	250-W	336	
7	15.19	15.14	25-D	139	142± 13
8	15.11	15.10	25-D	156	
9	14.79	14.82	25-D	131	
10	15.65	15.65	25-W	156	149± 7
11	15.38	15.32	25-W	143	
12	15.50	15.47	25-W	148	

*Status: i.e. $\frac{250\text{-}D}{mR - \text{dry/wet (W)}}$

**Gross reading not converted to mR

+Set of data obtained on Victoreen Model 2800 reader

++Set of data obtained on Victoreen Model 2810 reader

Table II. Effects of Solvents on CaF_2 (TLD-200) Response

SOLVENT: ETHYL ALCOHOL

TIME IN SOLUTION: 3 DAYS

TLD	Wt. Before (mg)	Wt. After (mg)	Status*	Reading**	Avg.
C (CaF_2,chip)					
1	27.49	27.49	250-D	930++	
2	27.31	27.31	250-D	820	870± 60
3	28.02	27.87	250-D	850	
4	28.71	28.63	250-W	820	
5	27.80	27.78	250-W	800	820± 20
6	26.81	26.82	250-W	840	
7	28.27	28.25	25-D	329	
8	26.72	26.73	25-D	327	328± 1
9	28.74	28.79	25-D	327	
10	27.25	27.25	25-W	255	
11	25.62	25.61	25-W	252	254± 2
12	27.83	27.84	25-W	---	
D (CaF_2,rod)					
1	19.26	19.20	250-D	660+	
2	18.82	18.84	250-D	610	650± 40
3	19.32	19.30	250-D	690	
4	19.10	19.09	250-W	690	
5	18.48	18.48	250-W	730	700± 30
6	19.31	19.33	250-W	670	
7	18.83	18.86	25-D	107	
8	19.14	19.09	25-D	115	113± 5
9	19.55	19.54	25-D	116	
10	18.91	18.89	25-W	115	
11	19.07	19.05	25-W	113	115± 2
12	19.05	18.97	25-W	116	

*Status: i.e. $\frac{250\text{-}D}{mR - dry/wet\ (W)}$

**Gross reading not converted to mR

+Set of data obtained on Victoreen Model 2800 reader.

++Set of data obtained on Victoreen Model 2810 reader.

this point unexplained.

In a second experiment, a small number of LiF chips and CaF_2 rods were placed in benzene. The basic procedure outlined above was followed. The TLD materials were exposed to 210 mR, dry. Then three of each type TLD were soaked in a benzene solution for five days. The data (Table III) are inconclusive but it appears that benzene has no effect on the TLD response.

LiF was selected as the TL material for use in the PAC-TLD mixture. For this reason, additional studies were conducted with LiF chips. In this study 24 TLD-100 chips were selected for use. The chips were washed in warm trichloroethylene, rinsed with warm methanol and air dried before annealing. The anneal procedure called for 15 minutes at 360°C followed by slow cooling.

After cooling each chip was weighed on an analytical balance. Groups of five chips were placed in test tubes containing 10 ml. of acetone, tertiary butyl alcohol, carbon tetrachloride, or a 16-carbon chain alkyl chloride and a group of four chips was included as the "in air" control. All five containers were exposed to approximately 500 mR of ^{60}Co radiation and set aside for future reading. The reading times post-irradiation were 1 hour, 1, 2, 3, 4, and 8 days.

Before readout chips removed from the solutions were subjected to the following treatment:

a) wash with warm trichloroethylene

b) rinse with warm methanol

c) vacuum filter in a Buchner funnel, this also serves to air dry the TLDs

d) heat treat in oven at 100°C for 1 ½ - 2 minutes (this is similar to the "pre-read" anneal used in most TLD readers).

Table III. Effects of Solvents on TLD-100 and TLD-200 Response

SOLVENT: BENZENE

TLD	Wt. Before (mg)	Wt. After (mg)	Reading[++]	Avg.	Soak Time[*]
A (LiF,chips)					
9	23.17	----	237		Dry
10	23.09	23.14	198		5 days
11	23.18	23.17	228	207±18	5 days
12	23.14	23.15	196		5 days
D (CaF_2,rods)					
9	19.57	----	454		Dry
10	18.96	18.94	504		5 days
11	19.11	19.10	438	474±33	5 days
12	19.02	19.05	480		5 days

[*] All TLDs were exposed dry, to an approximate exposure of 210 mR.

[++] Set of data obtained on Victoreen Model 2810 Reader, not converted to mR.

After this treatment, the TLDs were evaluated on a Victoreen Model 2800 TLD reader after which they were reweighed. All chips were then re-irradiated at the same exposure level (about 500 mR) to investigate glow curve structure which may not have been evident from changes in the digital readout. Table IV shows the weights of the TLD-100 chips before and after treatment and Table V gives the exposure data obtained in the experiment. The data exhibit some variation, for example the data for the butanol, but with the small amount of data these variations may be considered to be within the normal variations expected in a batch of TLDs. To check this further the experiment will be repeated with larger numbers of TLD chips in each group.

Some effort has been invested in preparing TLD materials in the laboratory. This effort was intended to provide low-cost TLD material for use in initial studies of mixing, molding, and recovery with the PAC-TLD paste. These TLD materials would be selected to be easily prepared from standard laboratory reagents yet exhibit stable properties in terms of sensitivity, fading, etc.

Calcium sulfate TLD crystals have been prepared according to the method of Bapat.[18] This technique is a modification of that reported by Yamashita et al.[19] The general procedure is as follows:

1) Combine weighed amounts of either $CaSO_4$ or $CaCO_3$ with the dopant impurity and mix well. In the initial study 8 grams of $CaSO_4$ were mixed with 15 milligrams of DyO (99.999% pure). This produces $CaSO_4$ crystals with about 0.2% w/w of Dy.

2) Add a small amount of concentrated H_2SO_4 to make a paste. Continue adding the acid and stirring in steps until a clear liquid is obtained. It may be necessary to raise the temperature of the solution to accomplish this.

Table IV. Effects of Selected Solvents on TLD-100 Chips

In Air (gm)	Acetone (gm)	Butanol (gm)	Carbon tetrachloride (gm)	16 C Alkyl chloride (gm)	Soaking Time
BEFORE SOAKING					
0.023	0.022	0.023	0.023	0.023	1 hr
0.023	0.022	0.022	0.023	0.023	1 day
0.022	0.022	0.022	0.022	0.022	2
0.023	0.023	0.023	0.023	0.023	4
	0.022	0.023	0.023	0.022	8
AVG.					
0.0228	0.0222	0.0226	0.0228	0.0226	
STD. DEV.					
±0.0005	±0.0004	±0.0005	±0.0004	±0.0005	
AFTER SOAKING					
0.023	0.023	0.023	0.023	0.023	1 hr
0.022	0.023	0.023	0.022	0.022	1 day
0.023	0.022	0.022	0.023	0.023	2
0.023	0.023	0.023	0.022	0.022	4
	0.023	0.023	0.023	0.023	8
AVG.					
0.0228	0.0228	0.0228	0.0226	0.0226	
STD. DEV.					
±0.0005	±0.0004	±0.0004	±0.0005	±0.0005	

Table V. Measured Exposure for TLD-100 Chips in Selected Solvents

Soaking Time	In Air (mR)	Acetone (mR)	Butanol (mR)	Carbon tetra-chloride (mR)	16 Carbon alkyl chloride (mR)	Avg. & Std. Dev.
1 hr	590	570	540	600	540	568 ± 28
1 day	550	570	540	580	570	562 ± 16
2	540	550	530	570	510	540 ± 22
4	560	530	530	570	500	538 ± 28
8		550	530	570	540	548 ± 17
AVG	560	554	534	578	532	
STD. DEV.	±22	±17	±5	±13	±28	

3) Filter this solution to remove impurities.

4) Evaporate to dryness slowly in a fume hood.

5) Wash the crystals repeatedly with distilled water to remove traces of H_2SO_4. The crystals may initially be a light brownish color but this step produces good quality, white crystals.

6) Dry crystals under a heat lamp or in an oven at 150°C.

7) Before use heat treat the crystals in an oven for one hour each at 300, 400, 500, and 600 °C.

Crystals produced according to the above procedure may be ground to produce a grain size distribution similar to that of commercially available TLD materials. Any dopant which can be obtained in sufficient purity can be used. The range of dopants concentrations is normally 0.01 to 2 % w/w depending on the desired characteristics.

Within the next year it is planned that these studies will be expanded to investigate the effects of solvents on the powdered material. Based on preliminary measurements and on a literature review of TLD research since 1972 it is clear that this phase of the work will concentrate on LiF (TLD-100) and $Li_2B_4O_7$ (TLD-800).

B. Investigation of Mixing and Molding Techniques

This phase of the research was begun only recently. Large samples of an n-alkyl chloride have been obtained from a commercial vendor and molding investigations are underway. Initial results obtained indicate that the anticipated problems of release from molds, etc. will be minimal. The PAC material when solidified does not adhere to glass or metal at all. Because of these results arrangement have been made with the Oak Ridge National Laboratory to obtain, on a loan basis, the molds used to fabricate certain internal organs of the MR. ADAM phantom. Three organs will be studied

first. These are the kidneys, liver, and lung. For the lung, considerations must also be given to preparing a "detector-organ" with a reduced density. This phase of the research is expected to proceed rapdily.

Until receipt of the organ molds, research on the uniformity of mixing and recovery efficiency will continue. At present, materials which have essentially the same density as LiF powder are used to provide a qualitative evaluation of the uniformity of mixing. These materials are selected because they are colored and therefore standout clearly against the white PAC matrix.

It is planned that two investigations will be carried out. First, large cylindrical shapes will be molded with the PAC paste and the LiF-substitute material. After setting the cylinder of PAC will be sectioned, the suspended material recovered, dried and weighed. This should give an indication of the degree of mixing uniformity. Preliminary results indicate that a uniform mixture can be obtained if the procedures outlined by Feher[20] are followed carefully.

A second experiment will be carried out to investigate the use of neutron activation analysis coupled with autoradiography to demonstrate uniform mixing. As before the substitute material will be mixed with the PAC paste in cylindrical geometry. After setting, the cylinder will be sectioned and the sections irradiated in the Georgia Tech Research Reactor. After irradiation the sections will be placed on photographic films for autoradiographic evaluation. An alternate method of evaluation being considered is to determine the induced activity of each section..

Work on the recovery efficiency of the LiF powder has been delayed primarily due to the cost of LiF powder. This phase of the research will

not be initiated until all other phases of this investigation is complete. However, studies using $CaSO_4$:Dy will begin soon.

C. Investigation into Other Methods of Dosimetry

During the past year three major literature surveys have been completed which are related in some manner to the research project. First, a careful survey of the nuclear medicine literature has been completed.[21] This survey collected information necessary to identify organs and radionuclides which should be studied in subsequent experiments. In addition, some information on organ shapes, sizes, locations, etc. was collected and summarized for selected organs. These data will be useful in the extension of the organ-molding phase beyond the organ shapes employed in the MR. ADAM phantom

A second literature survey has been completed on thermoluminescent dosimetry. This survey was designed to include primarily progress in the area since publication of the last TLD bibliography.[22] Initially this survey concentrated primarily on LiF but information on other phosphors has been collected. This bibliography will be submitted for publication in the open literature.

The third literature survey was intended to identify other techniques applicable to measuring "organ-averaged" doses in heterogeneous phantoms. In addition to the tetrachloroethylene-water two-phase system identified earlier,[13] the survey has identified another system reported recently by Gupta et al.[23] This system, called the ferrous sulfate-benzoic acid-xylenol orange system, has been used in the dose range 0.1 to 3000 rad. Many of the characteristics of this system are similar to the Fricke dosimeter.

This literature survey will continue and will concentrate primarily on liquid chemical dosimeters because of the requirement of tissue-equivalence.

D. Establishment of a Computer Capability

At the present time this task has been completed. The computer program, ALGAM,[24] has been installed on the Georgia Tech computer. Extensive modifications were required to obtain a working code due to the differences between IBM and CDC FORTRAN. However, test cases supplied with the program package have been run and results indicate that the code is functioning properly.

Some effort has been invested in expanding the documentation of the code. This code is quite large and documentation available with the code package was not adequate.

A second computer code, TECALC,[25] has also been installed on the computer system. This code is used to compute photon cross-sections for "equivalent" materials. Photon cross-sections may be calculated for tissue-, bone-, or lung-equivalent materials over the energy range 10 keV to 1 MeV. These cross-sections are then compared to those formulations used in the Monte Carlo calculations. Over the last few months, a comparison has been completed of those normally accepted "equivalent materials" to the Snyder-Fisher formulation. This evaluation has included 12 of the most common tissue equivalent formulations. This work will be continued and the useful energy range of the cross-section calculation will be extended to about 1.5 to 2 MeV.

The code DISDOS[26] is being maintained on the computer as a back-up to ALGAM. This code is an earlier version of ALGAM but the capabilities of the code are not so extensive.

Relationship to Other Projects

During the past year there has been significant collaboration with personnel in the Health and Safety Research Division at the Oak Ridge National Laboratory (ORNL). This project is of interest to ORNL because of the early developments in internal dosimetry at the Laboratory and the need to provide experimental data for comparison to Monte Carlo results.

Discussions have been held with ORNL personnel and staff members at the University of Chicago Hospital. A joint research program is being formulated to utilize the expertise of each group while minimizing the duplication of effort. This cooperation will be continued and a comprehensive research program will be formulated.

The principal investigator is a member of the Society of Nuclear Medicine's Medical Internal Radiation Dose (MIRD) Committee. In addition, he is an active member of NCRP Scientific Committee 55 on the Experimental Verification of Internal Dosimetry Calculations. Both these groups are aware of this ongoing research project and have input to the formulation of research plans to provide the necessary data. These are important links in that the groups are on the forefront of the field and can provide the guidance and feedback required for such a research program.

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